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13. ABSTRACT (Maximum 200 words)

Previous functional neuroimaging studies have implicated a fronto-parietal network in the control of visual attention. Here, we describe a series of attentional cueing studies which further investigate how this network allocates attentional resources to behaviorally relevant stimuli. In the first study, this network was shown to be involved in both spatial and non-spatial attention, with certain areas playing a greater role in spatial attention. The second study revealed that medial subregions of this network play a specific role in attentional orienting, while lateral subregions participate in more general aspects of cue processing, such as cue interpretation. A follow-up ERP cueing study demonstrated that frontal activity precedes parietal, consistent with theories that frontal regions communicate task goals to posterior brain areas. Another pair of cueing studies investigated how target discrimination difficulty modulates attention-related brain activity. Discrimination difficulty increased target-related activity; however, fronto-parietal responses to cues providing advance information as to the likely difficulty of an upcoming target discrimination did not vary as a function of expected difficulty. Lastly, in a study of attention to the global vs. local features of visual objects, the presence of distracting information during target discrimination resulted in reactivation of portions of the attentional orienting network.

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# FINAL PROGRESS REPORT

**(1) Foreword (optional)**

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**(2) Table of Contents (if report is more than 10 pages)**

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**(3) List of Appendixes, Illustrations and Tables (if applicable)**

N/A

**(4) Statement of the problem studied**

Previous functional neuroimaging studies have suggested that a fronto-parietal network is involved with the control of visual attention. Here we describe a series of studies investigating the mechanisms by which the brain controls the allocation of attentional resources, including differences between the control of spatial vs. nonspatial visual attention, the differential functions of various subregions of the attentional control network, and the influence of difficulty and distracting stimuli on attentional control processes.

**(5) Summary of the most important results**

**1. Neural mechanisms of top-down control during spatial and feature attention**

Theories of visual selective attention posit that both spatial location and nonspatial stimulus features (e.g., color) are elementary dimensions upon which top-down attentional control mechanisms can selectively influence visual processing. Neuropsychological and neuroimaging studies have demonstrated that regions of superior frontal and parietal cortex are critically involved in the control of visual-spatial attention (Hopfinger et al., 2000; Corbetta et al., 2000; reviewed in Corbetta and Shulman, 2002). This frontoparietal control network has also been found to be activated when attention is oriented to nonspatial stimulus features (e.g., motion). To test the generality of the frontoparietal network in attentional control, we directly compared spatial and nonspatial attention in a cuing paradigm. Event-related functional MRI (fMRI) methods permitted the isolation of attentional control activity during orienting to a location or to a nonspatial stimulus feature (color). Portions of the frontoparietal network were commonly activated to the spatial and nonspatial cues. However, direct statistical comparisons of cue-related activity revealed subregions of the frontoparietal network that were significantly more active during spatial than nonspatial orienting when all other stimulus, task and attentional factors were equated. No regions of the frontal-parietal network were more active for nonspatial cues in comparison to spatial cues. These findings support models suggesting that subregions of the frontal-parietal network are highly specific for controlling spatial selective attention.

*This work was presented in several international meetings and has been published as a full manuscript in Neuroimage (Giesbrecht et al., 2003).*

**2. Fast-rate attentional cueing using fMRI: Functional parcellation of attention control regions of the brain.**

Several recent studies using cued attention paradigms and event-related fMRI have provided strong evidence for the involvement of a fronto-parietal network in attentional control (Hopfinger et al., 2000; Corbetta et al., 2000; reviewed in Corbetta and Shulman, 2002). In the present study, we pursued further investigation of these attentional control systems. In particular, we employed additional controls for non-attentional sensory and interpretative aspects of cue processing to determine whether distinct regions in the fronto-parietal network are involved in different aspects of cue processing such as cue-symbol interpretation and attentional orienting. In addition, we used shorter SOAs (~1-1.5 sec) that were much closer than had been previously used to those in the behavioral and ERP cueing literature. Twenty participants performed a cued spatial attention task while brain activity was recorded with fMRI. We found functional specialization for different aspects of cue processing in the lateral and medial subregions of the frontal and parietal cortex, with the medial subregions being more specific to the orienting of visual spatial attention while the lateral subregions were activated by more general aspects of cue processing, such as cue interpretation. Additional cue-related effects included differential activations in midline frontal regions and pre-target enhancements in thalamus and early visual cortical areas.

*This work was presented in several international meetings (see below) and has just recently been published as a full manuscript in the Journal of Cognitive Neuroscience (Woldorff et al., 2004.)*

**3. High-resolution temporal characteristics of executive control of visual-spatial attention (ERPs)**

Recently, various fMRI studies have investigated the brain areas involved in the executive control of attention (reviewed in Corbetta and Shulman, 2002), and our fMRI study described above extends this literature. Much less, however, is known about the temporal characteristics of these activations. To obtain such temporal information, we recorded ERPs while participants performed the same covert spatial attention paradigm described above. The trial design structure was hierarchical, as in the corresponding fMRI experiment. More specifically, there were attend-cue-plus-target trials and attend-cue-only trials (left and right), as well as "interpret-cue" trials ("P": do not attend for possible upcoming target), and "nostim"-trials (for estimating and removing overlapping brain responses). Our results indicate that attention-directing and interpret-cues elicit very similar electrical activity over frontal and parietal scalp during the first 400 msec after stimulus onset, presumably reflecting general cue-symbol processing and interpretation activity. In the contrast between attend-cue and interpret-cue trials, however, this activity subtracted away, leaving a rising negative wave beginning at ~400 msec and lasting throughout the cue-target period. This later activity is presumably more specific for the spatial orienting of attention, like the medial frontal and medial parietal activations we observed with fMRI above. Moreover, both the scalp-distributions and the fMRI-seeded source estimation for this orienting-related activity suggest that the initial part at 400 msec derives from the frontal cortical sources, with the parietal activity not coming into play until ~300 mec later, results consistent with theories that frontal regions communicate task goals to posterior brain areas.

*This work was presented at the Cognitive Neuroscience Society Meeting this past and the corresponding manuscript is in preparation. (Grent-'t-Jong and Woldorff, in prep).*

**4. Perceptual task difficulty, attentional control, and target processing**

In line with a recent proposal that allocating greater attention to stimuli of interest reduces interference from irrelevant events (e.g., Lavie, 1995), prior studies have shown that increasing perceptual load leads to greater activity in the fronto-parietal network (Jovicich et al., 2001) and to reduced activity in regions that process distracter stimuli (Rees et al., 1997). In two experiments, we used fMRI to investigate whether expecting to perform a task with high perceptual load leads to greater activity in the fronto-parietal network or, alternatively, whether greater fronto-parietal activity occurs only when an actual task is performed. In Experiment 1, subjects ($N$=12) were cued on a trial-by-trial basis to both the location and discrimination difficulty for a possible upcoming visual target using a hierarchical trial structure resembling those in our other fast-rate cueing paradigms. We hypothesized that if participants are able to allocate greater attention to stimuli of interest when they expect to perform a difficult discrimination, then areas in the fronto-parietal network involved in attentional orienting should show greater levels of activity in response to the hard versus the easy cues. On the other hand, if allocating greater attention to expected hard-to-discriminate targets is not possible, then instead of observing such cue differences, we should observe differential activity only to hard vs. easy targets. Results showed that while cues in general did activate the fronto-parietal network, there were no meaningful differences in activity as a function of cued difficulty. However, differential target activity (hard > easy) was seen in several areas, including the anterior insula (bilaterally), the left inferior frontal sulcus, the superior parietal cortex (bilaterally), and the anterior cingulate cortex.

In a second experiment (n=16), we presented only a single level of target discrimination difficulty per run, wherein only the location of the upcoming target was cued in each trial. This design maximized the opportunity for participants to use different strategies in the easy versus hard runs, but, as in Experiment 1, no differential activity in the fronto-parietal network was observed for hard versus easy task cues while differences in target processing (hard > easy) were ***again*** observed in several areas, including the anterior insula (bilaterally), the left inferior parietal lobule (IPL), and the left inferior frontal gyrus (IFG). These experiments suggest that participants do not generally allocate greater attentional resources toward stimuli of interest in expectation of receiving a high perceptual load target. Moreover, they suggest that the principle source of the difficulty effects in the Jovicich et al. (2001) study was from the target processing aspects of their task rather than differential recruitment of attentional control networks brought about by expecting to perform a difficult task. Our results and those of Jovicich et al., (2001) concur with additional findings from our laboratory indicating that the presence of highly distracting stimuli during the performance of an attentional task increases the activity of frontal and parietal regions involved in orienting attention to targets, which helps to filter out those distracting events (Weissman et al., submitted – described in this report below; also see Weissman et al., 2002).

*The work from the two target difficulty studies described above is currently in preparation (Nelson et al., in prep).*

**5. Executive control of attention to global vs. local features and its influence on perceptual/response conflict**

In everyday life, we often focus greater attention on behaviorally-relevant stimuli to limit the processing of distracting events. For example, when distracting voices intrude upon a conversation at a noisy social gathering, we concentrate more attention on the speaker of interest to better comprehend his or her speech. In the present study, we investigated whether dorsal regions of the anterior cingulate cortex (dACC), thought to make a major contribution to cognitive control, boost attentional resources toward behaviorally-relevant stimuli as a means for limiting the processing of distracting events. Subjects (n=16) performed a cued global/local selective attention task while brain activity was recorded with event-related fMRI. Consistent with our hypotheses, greater dACC activity during target processing in the face of concurrent distracting events predicted reduced behavioral measures of interference from those same events. Activity in this area also was enhanced for cues to attend to global vs. local features of upcoming visual objects, further indicating a role in directing attention toward task-relevant stimuli. These findings indicate a role for dACC in focusing attention on behaviorally-relevant stimuli, especially when our behavioral goals are being undermined by distracting events.

*This work has been presented at meetings and is now submitted for publication (Weissman et al., submitted).*

**(6) Listing of all publications and technical reports supported under this grant or contract.**

**(a) Papers published in peer-reviewed journals**

Giesbrecht, B., Woldorff, M.G., Fichtenholtz, H.M., Song, A.W., Mangun, G.R. Neural mechanisms of top-down control during spatial and feature attention. *Neuroimage, 19:* 496-512, 2003.

Woldorff, M.G., Hazlett, C., Fichtenholtz, H.M., Weissman, D., Dale, A., Song, A.W. Functional parcellation of attentional control regions of the human brain. *J. Cog. Neurosci. 16:* 149-165, 2004.

**(b) Papers published in non-peer-reviewed journals or in conference proceedings**

Woldorff, M.G., Fichtenholtz, H.M., Song, A.W., & Mangun, G.R. (2001). Separation of cue- and target-related processing in a fast-rate compound-event visual attention cueing paradigm. *Cognitive Neuroscience Society Abstracts, 2001.*

Woldorff, M.G., Fichenholtz, H.M., Song, A.W., Mangun, G.R. (2001). Cue- and target-related processing in a fast-rate cued visual spatial attention paradigm. *Proceedings from Human Brain Mapping Conf.,* 2001.

Giesbrecht, B., Woldorff, M.G., Fichtenholtz, H.M., Mangun, G.R. (2001). Dissociating the neural control systems of spatial and nonspatial visual selective attention. *Society for Neurosciences Abstracts, 2002.*

Giesbrecht, B., Woldorff, M.G., Mangun, G.R. (2002). Cortical consequences of top-down control during spatial and nonspatial attention. *Society for Neurosciences Abstracts, 2002.*

Woldorff, M.G., Grent t'Jong, T. High resolution temporal characteristics of brain regions involved in top-down control of visual spatial attention. *Cognitive Neurosciences Society Abstracts, 2003.*

Weissman, D.H., Gopalakrishnan, A., Hazlett, C.J., Woldorff, M.G**.** (2003). The role of human anterior cingulate cortex in attentional control. *Society for Neurosciences Abstracts, 2003.*

**(c) Papers presented at meetings, but not published in conference proceedings.**

N/A

**(d) Manuscripts submitted, but not published**

Weissman, D.H., Gopalakrishnan, A., Hazlett, C.J., Woldorff, M.G. Conflict monitoring versus voluntary attentional orienting: An fMRI investigation of human anterior cingulate cortex's role in attention. *Submitted.*

**(e) Technical reports submitted to ARO**

N/A

**(7) List of all participating scientific personnel, showing any advanced degrees earned by them while employed on the project.**

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George R. Mangun, Ph.D.

Barry Giesbrecht, Ph.D.

Mike Nelson, Ph.D.

Daniel Weissman, Ph.D.

*No advanced degrees earned by scientific personnel while engaged in this project.*

**(8) Report of Inventions (by title only)**

N/A

**(9) Bibliography**

Corbetta, M., Kincade, J.M., Ollinger, J.M., McAvoy, M.P., and Shulman, G.L. (2000). Voluntary orienting is dissociated from target detection in human posterior parietal cortex. *Nat. Neurosci., 3,* 292-297.

Corbetta, M., Shulman, G.L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nat. Rev. Neurosci. 3,* 215-229.

Hopfinger, J.B., Buonocore, M.H. and Mangun, G.R. (2000). The neural mechanisms of top-down attentional control. *Nat. Neurosci., 3,* 284-291.

Jovicich, J., Peters, R. J., Koch, C., Braun, J., Chang, L., & Ernst, T. (2001). Brain areas specific for attentional load in a motion-tracking task. *Journal of Cognitive Neuroscience*, *13*, 1048-1058.

Lavie N (1995) Perceptual load as a necessary condition for selective attention. Journal of Experimental Psychology: Human Perception & Performance 21: 451-468

Rees G, Frith CD, Lavie N (1997) Modulating irrelevant motion perception by varying attentional load in an unrelated task. Science 278: 1616-1619

Weissman, D.H., Mangun, G.R., Woldorff, M.G. A role for top-down attentional orienting during interference between global and local aspects of hierarchical stimuli. *Neuroimage, 17:* 1266-1276, 2002.

**(10) Appendixes**

N/A